The Design and Implementation of Smart Battery Management System Balance Technology

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Abstract

To reduce the imbalance of Smart Battery and prolong the life of Smart Battery, the smart battery management system equalization charging protection system of battery series is designed. The imbalance reason of Li-Ion battery series and common balance technology was firstly analyzed, and then the battery balance principle based on X3100 chip was analyzed, and smart battery balance control circuit and software implementation were designed. According to the test, the balance design project can implement effectively the balance function of battery, and is characterized by low cost and simple circuit. It can be used in low power consumption equipment such as laptop computer and can improve the performance of battery and prolong the life of battery series.

Keywords: *Smart Battery, Balance Technology, Management System*

1. Introduction

Smart Battery is to realize the intelligence of battery on the base of common chemical battery and smart battery management system (or called communication control protection system). Smart Battery can monitor the state of battery and communicate directly with smart charger and tell the charge requirement to smart charger at any time. Smart Battery also can communicate directly with smart equipment (such as laptop computer mainframe) through SMBus. Using Smart Battery can indicate and monitor accurately the state of battery and prolong the life of battery. The key technology of Smart Battery is Smart Battery management system.

In 1995, Intel and Duracell proposed originally the definition of Smart Battery System. They two and many latter joined companies such as IBM, Sony and Sharp established together Smart Battery System Implementers Forum(SBS-IF) and constituted the composition, the function of each part, the format definition of parameters, communication ways and various protocols about Smart Battery System [1-4] and then the real application of Smart Battery System began. The system was firstly applied in laptop computer. After SBS-IF proposing the standard of Smart Battery, many companies joined in the study and application of the system and developed many projects which were applied widely in various portable equipments.

The early proposed and mature project was the BQ of TI. It used a MCU and a specialized measure and protection chip BQ29311 to realize the function of system and realized well the function of measure, calculation and protection for battery. Following the update of protocol, TI proposed series projects such as BQ2060, 2083, 2085. At present, TI still is the largest supplier of Smart Battery application, especially in the aspect of laptop computer in which TI takes up most share. But the products of TI were proposed earlier, though they were updated, they still had some disadvantage just as complex construct, low flexibility, high cost.

Otherwise, Microchip also proposed P301 project; Poweready proposed PowerSmart project; Japanese Mitsubishi proposed M61040 project. They were also pushed into market, but they were rarely applied comparatively.

Recently, American Intersil company proposed powerful X3100 chip[5] which integrated measure, protection and control to realize conveniently and effectively the management function of Smart Battery through the control of MCU.

Smart Battery balance technology is the key technology need to be resolved of Smart Battery management system. It plays an important role in prolonging the life of battery. Xia et al. [6] design the battery protection board which can provide over voltage, under voltage, over current and short circuit in discharge protection function for any package cells in series, and can realize equalizing charge for the whole package battery based on the chip of Texas Instruments BQ77PL90. Experiment and industry application results show that the equalizing charge and protection system has the features such as flexible application, stabilization, credibility, etc. The equalizing charge errors are less than 50 mV. Bonfiglio and Roessler [7] presented a method for active cell balancing of lithium ion battery stacks; it uses a flyback converter to pass charge from cell to cell with low losses and only a small cost increase from a typical passive system. Kamjanapiboon et al. [8] present an approach for balancing serially connected battery strings with high efficiency energy transferred. The efficiency of this balancing process is accomplished by channeling an excess energy through a DC Link Bus rather than done serially. The equalized efficiency of balancing process is increased more than the conventional techniques at least 12.80 percent. By applied this proposed technique to the charge equalized system, the unbalance charging problem can be eliminated. Wang et al. [9] develop an inexpensive, lightweight, durable, reliable, and predictable cell-balance algorithm (ICBA) with parallel-connected circuit to stabilize the respective cells and protect the battery management system (BMS).

Embedded systems technology is the mainstream circuit design technology[10-12]. This paper mainly introduces the implementation method of Smart Battery management system balance technology based on Embedded systems technology and chip X3100 in order to design Smart Battery management system with high efficiency, high reliability.

2. The Reason of Smart Battery Imbalance

In order to satisfy the requirement of the voltage and power of equipments, Li-Ion battery usually is the parallel connection of one or several battery series and each battery series is the serial connection of 3 or 4 batteries. Because of the inconsistency between each battery of battery series and the differences of each battery which is caused by the number of recharge cycles, the capacity of some battery decreases sharply. The capacity of battery series depends on the min capacity of each battery, so these differences will shorten the life of battery series. At present, the matching request for battery series is very high and it can reduce the influence of imbalance, but it can't solve the balance problem fundamentally. In order to solve the influence of imbalance on Li-Ion battery series, it needs to use equalization circuits in the process of recharge cycles.

The main reasons to cause the imbalance of battery are as follows[13][14][15]:

(1) In manufacturing process, because of technology,etc, the capacity and inner resistance of the batteries in the same batch exist differences.

(2) As time go on, the differences of battery capacity caused by the differences of self-contained discharge can't also be ignored.

(3) In using process, the differences of environment such as temperature and circuit board cause the imbalance of battery capacity.

(4) Before combining, the imperfect selection principles cause the imbalance between each battery.

It can be shown in **Fig.1**.

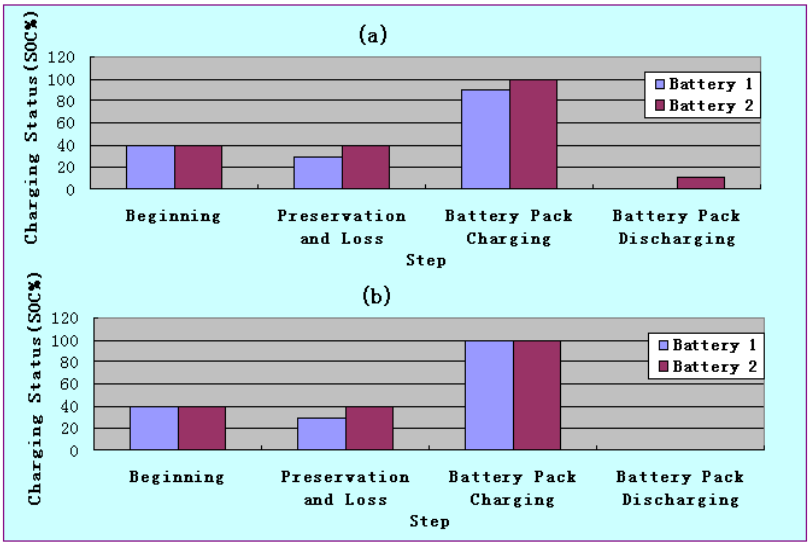

Fig 1. The imbalance reasons of **Li-Ion battery**

3. Battery Balance technology

According to the consumption of circuit on energy in balance process, current Li-Ion battery series balance control methods can be divided to 2 classes: energy dissipation type and energy no-dissipation type.

Energy dissipation type is that the excessive energies are consumed in the form of heat; energy no-dissipation is that the excessive energies are transferred or converted into other batteries; conversion efficiencies commonly reach 85%-95%**,** so this type can also consume 5%-15% energies **[15]**.

A. Energy dissipation type [15] [16]

Energy dissipation type is to bypass with resistance to realize equalization, shown in **Fig.2**. The type is characterized as following: the circuit structure is simple; the equalization process is usually completed in charge process; the low capacity battery can't be charged; the problems of energies waste and heat elimination management exist. Energy dissipation type usually has two ways [17]: one is constant shunt resistance equalization charge circuits, that is, a battery is in parallel with a shunt resistance constantly. The way is characterized as following: it has high reliability; the value of shunt resistance is very large; it uses fixed shunt to decrease the battery's differences which are caused by discharge; its defect is that shunt resistance consumes power constantly in the charge or discharge process of battery; So it is suitable to be used in the occasion that can replenish energies on time, such as satellite power. The other is switch control shunt resistance equalization charge circuits, that is, shunt resistance is controlled by switch and it begins to equalize when the voltage of a battery reaches cutoff voltage in the charge process. The equalization circuits works in the charge period, its characteristic is that it can shunt for the higher voltage of battery in charge process; it defect is that the limit of equalization circuits causes to produce lots of heat in shunt process, and these heat need to disperse.

B. Energy no-dissipation type [15]

The circuit structure of Energy no-dissipation type is complex relatively. The type usually has two ways: energy conversion equalization and energy transfer equalization.

Energy conversion equalization: By the signal of switch, the whole energy of Li-Ion battery series is supplied to a battery or transferring energy from individual cells to batteries, shown in **Fig.3 and Fig.4**.

Considering the cost and equalization efficiency, energy conversion type is mainly used in the occasion of middle or large power.

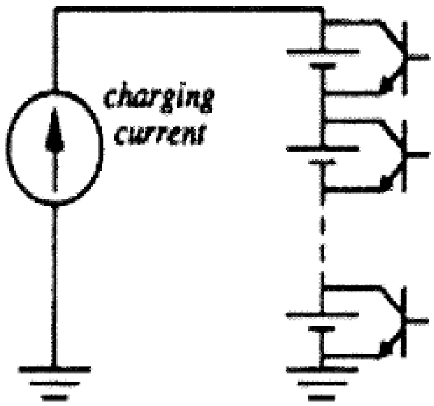

Fig 2. Bypass with resistance equalization

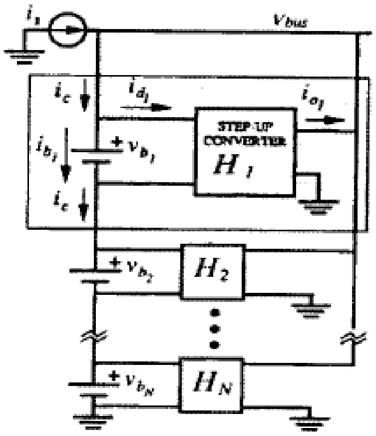

Fig 3. Transfer energy from individual Cells to batteries

Energy transfer equalization [18][19]: it makes use of storage components such as inductance and capacitor to transfer energies from high capacity individual to low capacity individual in Li-Ion battery series, shown in **Fig.5**. The circuit transfers the energies between the neighbor batteries by switching capacitor switches, and transfers the charge from high voltage to low voltage between batteries to achieve the purpose of equalization. Otherwise, the circuit can also implement two-way transfer between the neighbor batteries by the way of inductance storage. The circuit has small energy consumption, but it must transfer several times in equalization process, and it needs a long time to reach equalization, so it is not suitable to multi-series batteries.

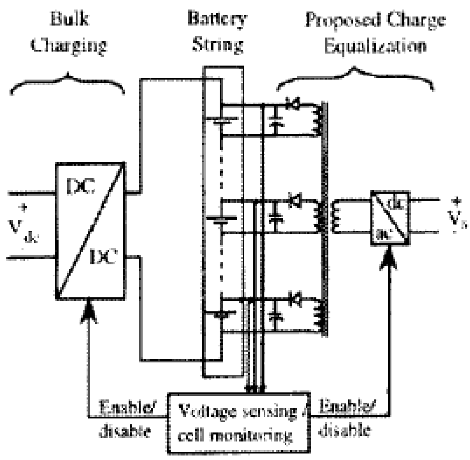

Fig 4. Proposed charging equalization

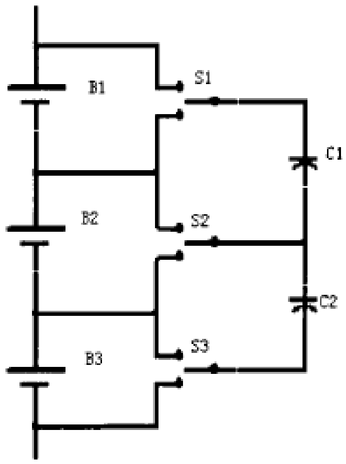

Fig 5. Shunt capacitor equalization

Otherwise, according to equalization function, Li-Ion battery series equalization circuit can also be divided into 3 classes: charge equalization, discharge equalization and dynamic equalization. Charge equalization is equalization the equalization in charge process, and it usually begins to reach equalization when the individual voltage of batteries reaches or excesses given voltage, and it decreases charge current to avoid over charge; discharge equalization is to avoid over discharge by supplying energy to the battery of low voltage in discharge process, meanwhile, the remaining capacity of other individual can be drained completely in discharge process because of adopting only discharge equalization; dynamic equalization combines the advantages of charge equalization and discharge equalization, and makes the battery series to reach equalization in the whole recharge cycles to avoid the problems in single equalization.

4. The Implementation of the Battery Balance Technology of Smart Battery Management System

A. The principle of realizing equalization based on X3100

The difference current is adopted in different batteries/battery series of serial batteries, and the imbalance between batteries can be decreased by bypassing the current of the highest voltage battery which needs to reach equalization, and it can achieve the purpose of a new matching. In order to avoid the extra consumption of power and decrease the time of equalization, it usually can be realized in charge process. The principle circuit is shown in **Fig.6**.

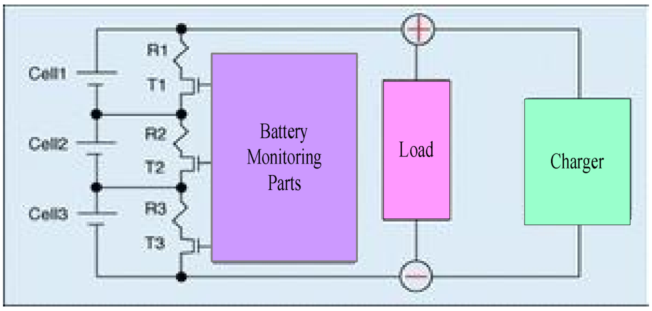

Fig 6. the realization principle of Li-Ion battery equalization

For example, if the voltage of Cell 1 is higher than the voltage of other cells and it needs to be equalized. In charge process, the conduction of transistor T1 can be controlled, and then there are shunt currents flows onto R1 to make the current which flows onto Cell 1 less than other cells. Thus after a period of time equalization, it will revise the imbalance between Cell 1 and other cells. For example, if the capacities of cell are 2000maH, shunt currents are 100ma, then after charging for 2 hours, it can revise 10% capacities.

At present, to deal with the equalization, it is in accordance with the shunt principle. But in specific hardware, sometimes the equalization circuit (R1, T1) is integrated to cell measure component, called inner integration; sometimes the outer separate components are adopted, called outer separation.

The problem should be paid attention: To avoid the error of measuring voltage, the intermission equalization action is adopted. The cell voltage should be measured when closing equalization circuit.

(1) Equalization action can be implemented in several recharge cycles.

(2) The influence of the inner resistance and power of bypass component should be paid attention.

B. Equalization control circuit

According to the theory of cell equalization, the project adopts typical shunt equalization way, and uses outer separation equalization structure to match the function of x3100. Each cell has the parallel circuit composed of R_{CB} and Q_B. QB is driven directly by equalization control interface of x3100, shown in **Fig.7**

Using external circuit and multiple equalization mechanism of x3100, the equalization functions of our project have outstanding advantages as follows:

(1) The equalization current can be selected. The cells of different capacity can realize the most reasonable equalization current by selecting suitable R_{CB}.

(2) It will not affect voltage measure of cells.

Several equalization circuits can be open simultaneity, so it improves the equalization efficiency extremely.

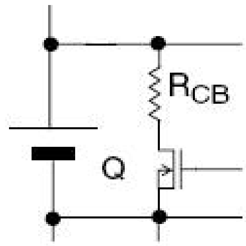

Fig 7. equalization control circuit of Li-Ion cells

C. Equalization control software flow

Shunt equalization circuit was adopted, and the equalization function was opened in charge process. Schmidt comparison judged by voltage difference, periodicity equalization control technology and high effective function control of completing equalization were used in the software. The software flow graph of equalization control is shown in **Fig.8.**

(1) Close equalization function when measuring that it is not charge and initialize equalization control register.

(2) In charge process, check the way of equalization control, and come into corresponding process program. In the beginning of each equalization period, check firstly that whether the voltage reaches the initial voltage of equalization or not.

(3) Check the Vdif between each cell with the cell of lowest voltage, to see that whether it needs to equalize or not. After measuring and comparing voltage twice, the cell needed equalization can be marked.

(4) After beginning to average, adopt Schmidt way to compare the voltage of stopping equalization. That is, if the Vdif which begins to equalization is 50mV, then the Vdif of stopping equalization is probably 25mV.

(5) Equalization adopts periodicity control, that is, 60s is a period. Here, equalization implements 40s and stops 20s.

After a period is over, implement the whole equalization judge process again.

The equalization control algorithm adopted by us is characterized by improving equalization efficiency and decreasing components heat. Meanwhile, Because of using outer equalization circuit way, according to the size of cell capacity, equalization current can select suitable resistance to reach the optimization.

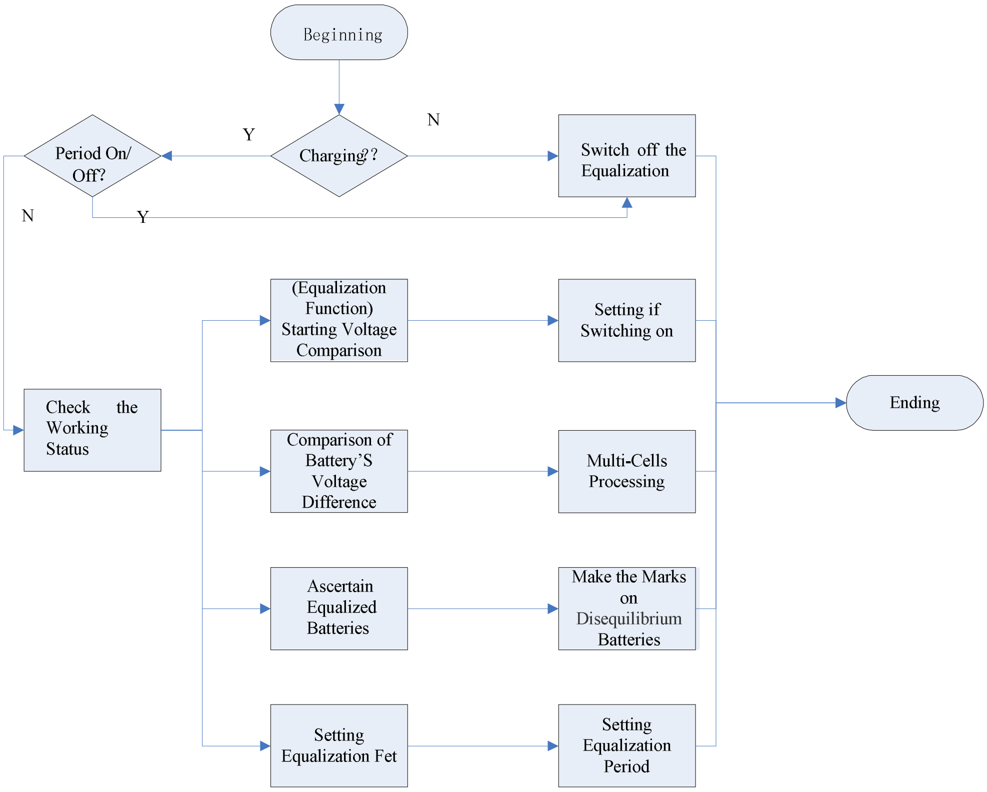

Fig 8. software flow of equalization control

D. Electric capacity measure

Electric capacity is one of the main parameters for cell. The unit of electric capacity is maH or 10mwH. Design electric capacity is a standard capacity of cells design; if the cell or connection way is different, then design electric capacity is different. System Remaining Capacity called RM for short is a parameter of identifying the change of system capacity. The parameters such as remaining charge/discharge time, system capacity percent are calculated according to RM. The overwhelming concern situations such as current energy status and using time state of Smart Battery can be got by RM.

RM is a changing parameter. In charge process, it increases continuously; in discharge process, it decreases gradually. The system was realized by continuous sampling current which was converted through integral to capacity change. So the ways of sampling and the methods of calculation have a great influence on the accuracy of RM.

(1) Current sampling

Electric capacity is the product of current and time:

$$C(mhA)=I(ma)\times T\ (Hour)$$

Another,

$$\Delta C(mhA)=I\times\Delta T$$

So, the calculation of RM is the calculation and accumulation of ΔC actually. That is, set suitable sampling time ΔT, measure current, and then calculate their product to get the changing value ΔC of RM within ΔT time in order to update the value of RM on time.

(2) Electric capacity calculation

The unit of electric capacity calculated according to measuring current is ma.ms. If the unit is directly converted into ma.H, then it will become to a very little decimal fraction, thus the value can not be got. The process technology of byte enlargement was adopted in our software; it can acquire accurate calculation result.

(3) The influence of system power-consumption and battery discharge on RM

Control system uses the battery as supply power, and its own energy consumption has a influence on RM. Li-Ion battery has also electric consumption, typically as 0.2%/day. When Smart Battery is on standing, the two electric consumption must be considered. Otherwise, it will bring the deviation of RM. In the design, RM was revised once at regular intervals.

(4) FCC self-study

FCC (Full Charge Capacity) is the capacity of battery which is filled with now. After being using several period, the performance of a series Battery will decrease, and its maximum electric capacity will also decrease. Thus Smart Battery needs to ascertain the change to get accurate status itself. This design will use FCC self-study technology in discharge process to acquire the maximum capacity and state of current battery.

E. The practical experiment of battery equalization

In order to the experiment of battery equalization, the 2200mah battery series of 3S1P was prepared, and a cell of it was drained until its voltage is less 100mV than other cells. Circuit used 40mA equalization current.

(1) Begin to charge, the voltage rises to equalization initialization voltage.

(2) Equalization actions begin. Cell 1 and Cell 3 implement the actions of equalization circuit.

(3) Implement equalization for 40s, close period actions for 20s.

After each cycle, the voltage was drained to static voltage about 3900mV. After 3 cycles, the experiment date is shown in **Table 1.**

Table 1. experiment date of battery equalization

Unit: mV	Vcell1	Vcell2	Vcell3
Initial state	3950	3846	3954
The first cycle	3976	3906	3982
The second cycle	3947	3883	3950
The third cycle	3942	3895	3945

After 3 cycles, it could see that the Vdiff from more than 100mV to 50mV, the performance of battery was also improved obviously.

5. Conclusions

Because of the influence of technology and working environment, serial individual of Li-Ion battery has inconsistency and it is easy to cause the imbalance of battery and decrease the life of battery. So, the smart battery management system equalization charging protection system of battery series was designed based on X3100. This system can improve the performance of battery obviously and prolong the life of battery. Its cost is low and its circuit is simple. This technology has been applied on several types of laptop computer such as IBM, SONY and it is in good working, and the good economic benefits are gained.

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